While some of these displacements must be attributed to temperature changes and effects entirely within the instrument, yet slow tiltings of the ground also occur, due to a variety of causes. The seismograph, as now installed, answers every purpose for the registration of distinctively earthquake movements, but the slow tiltings referred to can not be studied satisfactorily in the present location of the apparatus which for such purposes should be isolated as far as practicable.

OBSERVATIONS OF SOLAR RADIATION WITH THE ANGSTROM PYRHELIOMETER, AT PROVIDENCE, R. I.[1]

By Mr. HARVEY N. DAVIS, dated March 9, 1903.

During the fall of 1901 arrangements were made by Prof. Cleveland Abbe, on behalf of the United States Weather Bureau, and Prof. Carl Barus, of Brown University, for making a series of observations upon the amount of solar radiation received from day to day at the surface of the earth. An Ångström electric compensation pyrheliometer, No. 28, and a Weston milliamperemeter, No. 4315, were accordingly sent to Providence, R. I., and the work placed in my hands.

As an observing station we finally decided upon a room in the third story of a house situated in one of the highest parts of the city. The galvanometer, resistances, and batteries were permanently fastened to the wall just inside a southern window, while the sloping roof outside offered a convenient and exposed support for the tripod and pyrheliometer. When in position the observing tube was about 188 feet above sea level.

As is already well known,[2] the instrument consists essentially of two thin narrow strips of blackened platinum so mounted as to be exposable to the sun's radiation. While one is thus exposed the other is shielded and heated to the same temperature by the passage of an electric current of known intensity (usually .2 to .4 amperes), the ammeter and a variable resistance being included in the circuit. The desired equality of temperature is recognized by means of a secondary thermoelectric circuit, including a very sensitive galvanometer of the D'Arsonval type, and a constanten-copper thermal element, whose junctions are very close to, but electrically insulated from, the centers of the two strips. At first the instrument was used with its electrical connections just as they were packed, but a considerable shifting of the zero point of the galvanometer soon appeared, and seemed to be due to a set in the torsion suspension, caused by the extreme deflections to which so sensitive an instrument is liable, before the current strength can be properly regulated. On this account I was led to introduce a platinum key into the galvanometer circuit and to use a zero method, adjusting the current in the main circuit until no throw was observable when the key was closed. This key was almost immediately replaced by a mercury commutator, symmetrical with respect to the galvanometer and pyrheliometer tube, to avoid any spurious thermal E. M. F. in the circuit. It was also found convenient to modify the connections of the main circuit for various reasons, until it assumed a form schematically represented in fig. 1. P is the tube, C the commutator, and G the galvanometer of the thermo-couple circuit. In the main circuit r is the variable resistance (which could be made ∞) and M the ammeter supplied with the apparatus. R is a resistance box of considerable size, which was used, partly to cut down the current on cloudy days, and partly to keep two Daniels' cells (B) in condition when the apparatus was not in use. T is a mercury three-way key.

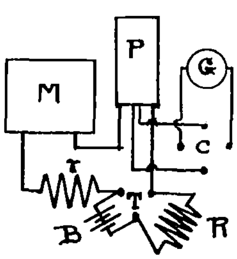

FIG. 1.

Early in December the behavior of the observing tube became very irregular, its resistance often becoming infinite for no apparent reason whatever. It was, therefore, returned to Washington and its contacts thoroughly examined, and, although no trouble could be found, the bad contact was in some way improved, for it functioned properly during the rest of the year.

During the summer of 1902 the writer was obliged to give up the work on account of his absence from the country, and Mr. Robinson Pierce, jr., also of Brown University, very kindly undertook it. The apparatus was moved to a similar situation at his home, a quarter of a mile away on the same ridge, the altitude of the tube being 163 feet. Here observations were made during July, August, and a part of September. Others were made later in September at the first place. Besides making these observations, Mr. Pierce has also carried through a considerable number of the calculations, whose results appear in the accompanying tables.

The method of observing was as follows: The tube was first set up and oriented, both strips being exposed to the sun, and the standard time, the neutral reading of the galvanometer (the key being open) and the temperature inside the tube were recorded. The "throw" when the key was closed was also observed, and both strips were exposed until this was a minimum, and usually very small. Two current determinations were then made, the first with the left-hand strip in the circuit and the second "switch right;" the tube's orientation was corrected; two more determinations were made, the first "switch right" and the second "switch left," and then the time, temperature, and zero point were again observed and recorded. The mean of four such current determinations was taken as the i of the set, corresponding to the mean time and the mean temperature. The total time necessary to complete a set was from four to eight minutes. The state of the sky was also recorded.

The sources of error to which such work is subject are very many. In the first place, a brisk breeze, if it were from the right direction and a bit gusty, was sometimes enough to cause a throw of 2 or 3 centimeters in a scale distance of some 50 centimeters, and the resulting error in the determination of radiation is 5 or 10 per cent. It is almost always possible, however, to take readings between times when the wind is gusty; when it is steady, the effect upon the mean i should be zero, so that this trouble is not particularly formidable if one does not care for accuracy within say 2 or 3 per cent. A further difficulty is caused, on all but the best days, by variations in the amount of heat absorbed by mists or clouds in the path of the sun's rays. If the cloud layers are at all thick, the resulting fluctuations in the radiation received are so considerable and so rapid that anything but the roughest kind of an approximation is at once impossible and meaningless. The presence of either of these difficulties is indicated in the accompanying tables by the words "readings variable," and when a full set of four determinations could not be obtained the resulting radiation number is marked with (?).

INVESTIGATION OF INSTRUMENTAL ERRORS.

Besides these meteorological troubles there were also instrumental ones to be reckoned with. The most obvious of these was a scale error in the ammeter, the pointer of which quite evidently read some 0.008 amperes too low when the instrument was first received. It was accordingly connected in series with a Thomson current balance, No. 134, a variable re-

[1] A similar report by Mr. H. H. Kimball will follow.—ED.

[2] See Prof. C. F. Marvin: "The measurement of sunshine and the preliminary examination of Ångström's pyrheliometer," MONTHLY WEATHER REVIEW, October, 1901.

See also Knut Ångström, Intensité de la Radiation Solaire—Recherches faites à Ténériffe, 1895 et 1896. Upsal, 1900.

See also K. Ångström, Nova Acta Upsal, 1893: The Physical Review, I, p. 365, 1893; Wied. Ann. 67, p. 636, 1899; Astrophysical Journal, 9, p. 334, 1899, and Annalen der Physik und Chemie, Neue Folge, Band 67 [1899], p. 633.

sistance (that supplied with the apparatus), and from one to fifteen cells of a large storage battery in the Brown laboratory, and several sets of comparisons were made covering the whole scale. In all, except the first few, the pointer of the ammeter was brought by means of the resistance exactly over a chosen scale division, which could be done with great accuracy, and the current balance was then adjusted and read to the nearest tenth of the smallest division of its accurate scale, the results being reduced by means of the tables supplied with the instrument and being accurate to within considerably less than one thousandth of an ampere, beyond which it was impossible to read the ammeter in actual use. Tenths of this unit were carried in the calculations although they could not be depended on as more than approximate. From a number of such observations made on November 18, 25, 26, and 27, 1901, it was at once evident that the trouble was not due to a bent pointer, for at 500 the error was practically zero; and further, that the correction curve, $x =$ a scale reading, $y =$ the corresponding correction, was by no means a straight line. Indeed, it was much more nearly two straight lines, and the break, as also an irregularity in the neighborhood of $x = 100$, were very probably not imaginary. In view of all this, we constructed an arbitrary table of corrections in thousandths of an ampere for each fiftieth division of the scale and interpolated when necessary. Each mean, i, was then corrected accordingly. At the same time it was noticed that when the ammeter was held vertically instead of horizontally the scale correction at zero was almost null, and so the instrument was investigated in this position, but it was found that although it was all right at both ends of the scale, yet in the middle it was just as bad in the one case as in the other, the new curve rising to the breaking point of the old one, with a similar irregularity at $x = 100$, and following the old curve almost exactly thereafter. Apparently the trouble was at least partly due to a poorly balanced shuttle. Still, the correction curve was quite definite and permanent, and so we concluded not to wait for repairs to the ammeter. The instrument was again thoroughly tested in April, 1902, and the curve obtained was essentially similar and showed the same two peculiarities. The various series of comparisons are shown in Table 1, as also the resulting table of corrections. The curves obtained are shown in fig. 2.

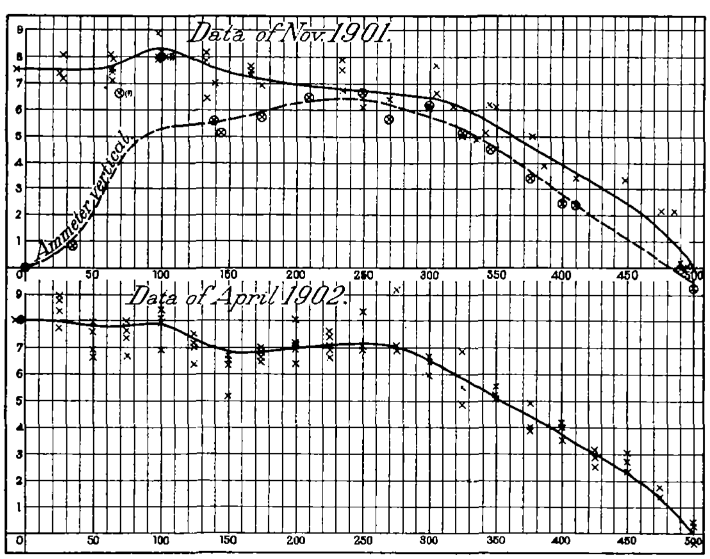

FIG. 2.

The peculiarities of the pyrheliometer itself were not so easily investigated. In the first place it was very early noticed that the current required to bring into equilibrium strip L, (the left hand strip, as one looks at the back of the tube) was, in general, considerably higher than the corresponding figures for strip R, under the same conditions. All the sets which were obtained in 1902, under favorable meteorological conditions, have been examined with this in view. If we call the four readings of a set, in their order A, B, C, and D (A and D being taken with the current through L), then the quantity $L - R = \frac{A + D}{2} - \frac{B + C}{2}$ was found to have an average value of $+ 22.6$ thousandths of an ampere, and it was negative in only five sets in a total of 232. The cause of this is still obscure. Of course such a discrepancy would arise if the strips were dissimilar in width, absorbing power, or specific resistance; but, as a matter of fact, the actual difference in width is far too small to account for the observed effect, and probably the same is true as to the other constants of the strips. Furthermore, during the last twenty observations an especial effort was made to work very slowly, from seven to thirteen minutes being used for a set of four readings, with the unexpected result that this quantity $L - R$, previously consistently

TABLE 1.—*Comparison of milliamperemeter No. 4315 with Thomson current balance No. 134.*

1901.

Scale reading.	Nov. 18. I. Correction.	November 25. II. Correction.	November 25. III. Correction.	November 25. IV. Correction.	Scale reading.	Nov. 26. V. Correction.	Nov. 27, vertical. VI. Correction.	Adopted corrections (used up to April 26). Scale reading.	Adopted corrections (used up to April 26). Correction.
28	+10.4*	+12.0*	+8.1	+7.2	− 7.5	+7.5	....	0	+8
64	7.5	8.1	7,5	7.1	0	....	0.0	50	8
98	....	8.8	8.0	+7.9	26	7.3	....	100	8
134	6.4	8.2	7.8		35	....	+0.7	150	7
167	7.3	7.4	7.6		65	7.9	....	200	7
236	6.7	7.8	+7.5		70	....	6.7†	250	6
306	6.6	7.7			100	8.1	8.1†	300	6
319	....	6.1			140	7.0	5.6	350	5
342	5.1	....			145	....	5.2	400	4
345	....	6.2			175	6.9	5.7	450	+2
350	....	6.1			210	6.6	6.6	500	0
377	5.0	....			250	6.1	6.7		
448	....	3.3			270	6.3	5.7		
475	....	+ 2.1			300	6.1	6.2		
485	+ 2.1	....			325	5.0	5.2		
					335	4.9	....		
					345	....	4.5		
					350	4.5	....		
					375	....	3.3		
					385	3.8	....		
					400	....	2.4		
					410	3.4	2.3		
					490	+0.2	−0.1		
					495	0.0	....		
					500	−0.1	−0.8		

NOTE.—Sets I, II, V, and VI were made with the medium weights on the balance. As thus used the balance has a range of .5 amperes, just that of the ammeter. Set III was made with the small set of weights and set IV without any weights at all.

*In the least sensitive part of the scale.

†Known to be too large. Pointer did not swing clear.

1902.

Scale reading.	April 25. I. Correction.	April 26. II. Correction.	April 26. II.	April 28. III. Correction. (Up.)	April 28. III. Correction. (Down.)	Adopted corrections (used after Apr. 26). Scale reading.	Adopted corrections (used after Apr. 26). Correction.
						− 8	+8.0
− 8	+8.0	+8.0		+8.8	+7.7	+ 25	8.5
+ 25	9.0	8.4		7.9	6.8	50	7.2
50	7.6	6.6		7.6	7.4	75	7.6
65	8.0	6.7		7.8	8.1	100	8.0
100	8.4	6.8		7.2	7.0	125	7.0
125	7.5	6.3		6.3	6.6	150	6.4
150	6.7	5.2		6.5	6.8	175	6.7
175	7.0	6.7		6.9	7.2	200	7.0
200	7.2	6.4	+8.2	6.6	7.4	225	7.2
225	7.6	6.8	7.1			250	7.4
250	7.0	8.3	6.9			275	7.4
275	6.9	9.3	7.0			300	6.8
300	6.5	6.7	5.9			325	5.8
325	4.7	4.7	6.8			350	4.8
350	5.2	5.5	5.1			375	4.2
375	4.8	4.0	3.8			400	3.8
400	3.5	4.0	4.1			425	2.8
425	2.8	3.2	2.5			450	2.7
450	2.4	2.7	3.0			475	+1.5
475	+1.3	1.7	1.3			500	0.0
500	−0.3	+0.4	+0.3				

Sets I and II with the medium weights; set III with the small weights.

large, was reduced to $+9.8$ thousandths of an ampere. It is, however, to be hoped that the individual errors in A, B, C, and D are largely eliminated in an arithmetic mean.

Another noticeable peculiarity was a sort of rhythm in the relative magnitudes of A, B, C, and D, D being almost invariably larger than A, and B than C. On the average, A was found to be 7.2 thousandths amperes greater than the mean of the four, B to be 9.4 and C 14.1 less than that mean, and D 16.4 greater, as is indicated in fig. 3. With this in

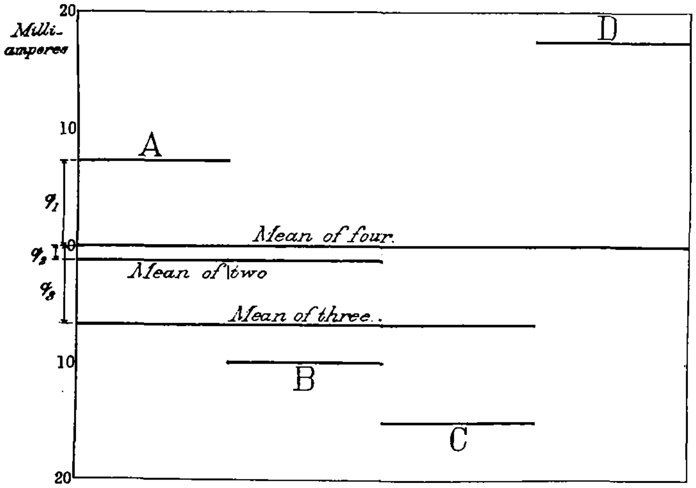

FIG. 3.

view, a careful record was kept during September of the direction and amount of the throw obtainable with both strips exposed just after each of the four determinations of a set. Almost invariably the strip which had just been heated by the current showed an excess of temperature, and this is probably the true cause of the shifting of the galvanometer zero, rather than any trouble in the suspension. This throw may be due merely to a difference in rates of cooling, in which case each determination, having been made by a zero method, would be correct; or it may be due to some cumulative action of the current either on the strips or on the thermal circuit, in which case each reading would be too high. In either case, if the four readings were made too close together, we should expect B and D to be too high and C too low, thus explaining the inequalities which have been mentioned, but we should not expect the mean of C and D to be higher than that of A and B, while, as a matter of fact, it averaged 2.3 thousandths amperes higher. The whole thing is so complicated that, until a satisfactory explanation of it is worked out, the arithmetic mean of the four determinations of a set must be regarded as the safest thing to work with, the results thus obtained being at least consistent. I have, however, obtained the average differences for each month, which are presented in Table 2, and from the weighted means of these averages have computed a set of corrections for the reduction of the mean of a defective set to "standard conditions," as follows:

$$q_1 = \text{mean} - A = -7.2;$$

$$q_2 = \text{mean} - \frac{A+B}{2} = +3.5;$$

$$q_3 = \text{mean} - \frac{A+B+C}{3} = +5.9.$$

I have also tried to get some idea of the consistency with which observations could be made by computing for each standard set the quantity $E = \frac{A+B}{2} - \frac{C+D}{2}$. The algebraic mean of these is $E = -2.3$ thousandths amperes, and the mean of their numerical values without regard to sign is $[E] = 5.5$ thousandths amperes. The "mean of the errors," in the least squares sense would be $\eta = \frac{[E]}{2} = 2.8$, which would give a probable error of 2.4, rather less than 1 per cent of the average reading. With experience and plenty of time between readings one could easily keep the probable error, *as thus calculated*, under one-half of 1 per cent; but, unfortunately, this does not mean very much. I do believe, however, that such observations can be relied upon within 3 or 4 per cent and that, for qualitative meteorological work, such an amount of accuracy is quite enough to make them of value.

TABLE 2.

Month.	Observer.	Number of observa'ns.	Values for $L-R$.	No. of obs. with neg. $L-R$.	Mean $-A$.	Mean $-B$.	Mean $-C$.	Mean $-D$.	E.	$[E]$.
January	H. N. D.	42	13.8	2	−5.3	7.7	9.8	−13.1	−3.0	4.9
February	do.	23	29.2	1	−10.4	10.5	17.7	−19.1	−0.8	5.0
March	do.	29	33.0	0	−10.0	13.4	19.9	−23.5	−3.6	4.4
April	do.	12	17.7	1	−4.8	4.8	12.9	−12.9	−0.1	6.4
May	do.	9	23.2	0	−3.7	7.5	13.6	−23.5	−6.1	6.1
June	do.	6	29.5	0	−8.8	13.2	21.0	−25.5	−4.5	5.8
July	R. P., jr	40	20.7	0	−7.9	8.3	12.6	−12.9	−0.4	6.0
August	do.	40	28.0	0	−7.0	11.4	16.8	−21.1	−4.1	6.5
September	do.	12	24.9	0	−5.6	9.8	15.0	−19.4	−4.4	5.4
*September	H. N. D.	19	9.8	1	−6.4	4.1	6.1	−3.7	+2.2	4.3
Totals	......	232	......	5	......	......	......	......	......	......
Weighted means			22.6	......	−7.2	9.4	14.1	−16.4	−2.3	5.5
Excluding *September			23.7	......	−7.2	9.9	14.9	−17.5	−2.7	5.5

RECORD OF OBSERVATIONS OF SOLAR RADIATION.

The determinations made, 267 in number, are presented in Table 3. The first column gives the date, and the second the local solar time T of each observation. In the third are the determinations themselves or Q in gram calories per minute and per square centimeter; these are calculated from the corrected means (i) of the currents observed, by Ångström's formula[3]

$$Q = \frac{r\,i^2}{4.19 \,.\, a \,.\, b}\,60 = k\,i^2$$

where r is the resistance per linear centimeter of the bands, b their width and a their absorbing power. The only one of these instrumental constants that could be verified was b, given as 0.150 cms. Direct measurements with a filar micrometer gave—

Right-hand band $b = 0.1482$ cm.
Left-hand band $b = 0.1493$ cm.
Average.... $b = 0.1488$ cm.

the discrepancy being quite negligible. In practise the factor k for any temperature was taken from the table given by Ångström. The figures in the fourth column N indicate the number of readings upon which the corresponding Q is based; in the absence of any figure, 4 (a normal set) is to be understood.

In the next three columns are the hour angle θ, the declination δ, and the zenith distance z of the sun. For δ the mean value for each day is used; a more accurate interpolation would have increased the labor of the subsequent computation very materially, while the improvement in the values of z would have been but slight. θ and z are calculated for each observation, the former from T, the latter by the formula

$$\cos z = \sin \theta \sin \delta + \cos \varphi \cos \delta \cos \theta$$

the results being given to the nearest five minutes.[4] φ was taken as 41° 50.′.

The remaining five columns give the accompanying meteorological conditions. Two sets of data were available, those taken at the Ladd Observatory under the direction of Profes-

[3] See Ångström's Teneriffe report, p. 7.

[4] For a graphical method of solving this equation for a large number of observations by means of a steorographic projection of the celestial sphere, see Radau Actinométrie. Paris, 1877, p. 31.

TABLE 3.—*Observations of solar radiation.*

Date.	T.	Q.	N.	ϑ.	δ.	Z.	Barometer.	Temperature.	Relative humidity.	Absolute humidity.	Weather.
					(South.)						
1901.	h. m.			° ′	° ′	° ′	Inches.	° F.	Per cent.	Grs. cu. ft.	
November 5	12:31	1.062	(?) 6	7 45	15 37	57 50	29.87	50	60	2.446	Cloudy.
6	12:26	0.310	...	6 30	15 55	58 05	.86	46	65	2.300	Cloudy; readings variable.
9	10:46	0.897	...	18 30	16 48	61 05	.88	49	58	2.346	
	12:42	0.643	...	10 30	...	59 25	.83	51	42	1.773	
	1:31	0.795	...	22 45	...	62 15	.82	50	45	1.834	
11	1:42	0.131	(?) 3	25 30	17 22	63 45	.96	43	38	1.271	
15	10:00	0.848	...	30 00	18 26	66 20	.36	40	60	1.709	
16	11:41	1.014	...	4 45	18 42	60 40	.57	45	50	1.707	Light clouds near horizon.
	11:48	1.078	...	3 00	...	60 35	.57	45	50	1.707	
	12:05	1.059	...	1 15	...	60 35	.57	45	50	1.707	
	12:31	1.043	8	7 45	...	60 55	.57	45	48	1.640	
21	12:56	1.143	...	14 00	19 53	63 05	30.05	40	52	1.632	
30	12:38	0.995	...	9 30	21 37	64 05	29.76	34	55	1.254	Hazy clouds near horizon.
	12:51	1.000	...	12 45	...	64 30	.77	34	55	1.254	
December 4	9:26	0.868	12	38 30	22 13	73 15	.57	23	96	1.362	Streaky clouds near horizon.
	2:47	0.842	6	41 45	...	74 45	.67	25	60	0.931	
5	9:00	0.656	...	45 00	22 21	76 30	.97	23	71	1.007	
	2:38	0.746	(?) 2	39 30	...	73 50	.97	24	51	0.757	
6	9:02	0.841	10	44 30	22 29	76 20	30.22	23	59	0.837	
1902.											
January 12	9:22	0.866	12	39 30	21 43	73 20	29.01	25	73	1.132	Hazy, some cirrus.
	10:31	1.025	8	22 15	...	66 50	.00	27	68	1.154	
	12:51	1.055	12	12 45	...	64 40	28.98	29	59	1.093	
	2:36	0.766	(?) 1	39 00	...	73 05	29.02	29	57	1.055	Cumuli.
13	8:41	0.346	...	49 45	21 33	78 20	.34	24	68	1.007	Fleecy haze.
	10:24	0.184	...	24 00	...	67 10	.35	22	63	0.854	Heavy haze.
	12:23	0.586	8	5 45	...	63 35	.34	24	58	0.860	Do.
	3:22	0.607	...	50 30	...	78 40	.36	25	57	0.884	Do.
14	8:37	0.725	6	50 45	21 23	78 40	.74	16	62	0.640	
	11:01	1.179	8	14 45	...	64 40	.78	23	44	0.623	
	12:19	1.160	8	4 45	...	63 20	.76	24	40	0.593	Very light haze.
	1:21	1.125	...	20 15	...	65 55	.76	25	37	0.573	
	2:58	0.954	8	44 30	...	75 25	.78	27	35	0.544	
15	8:52	0.577	8	47 00	21 12	76 35	.80	28	90	1.596	
	10:37	0.737	8	20 45	...	65 55	.78	37	74	1.837	Hazy clouds; readings variable.
16	9:57	0.321	...	30 45	21 01	69 00	.63	34	80	1.823	Heavy haze.
	2:59	0.553	8	44 45	...	75 15	.54	38	59	1.561	
17	8:50	0.503	...	47 30	20 50	76 30	.61	20	65	0.803	Fleecy clouds; readings variable.
	1:33	1.132	(?) 1	23 15	...	66 15	.60	28	48	0.851	Fine blue sky; instrument working poorly.
19	10:38	0.938	...	20 30	20 26	65 05	.74	36	60	1.474	Very light haze.
20	8:45	0.931	8	48 45	20 13	76 40	30.16	20	55	0.680	Fine sky.
	12:52	0.480	8	13 0	...	63 10	.12	31	50	1.011	Light streaky clouds.
25	8:29	0.856	8	52 45	19 04	78 05	.04	28	70	1.241	Light cirrus under the sun.
	10:34	1.085	8	21 30	...	64 05	.08	34	47	1.071	
	11:04	1.103	...	14 0	...	62 15	.07	34	46	1.049	Light haze.
	1:43	0.640	...	25 45	...	65 25	.07	36	50	1.228	
	3:00	0.524	8	45 0	...	73 45	.10	36	50	1.228	
28	8:34	0.914	8	51 30	18 19	76 40	.24	17	40	0.432	
	1:40	1.166	8	25 0	...	64 25	.24	20	39	0.482	
February 3	1:46	1.054	...	26 30	16 39	63 25	29.23	29	41	0.760	Haze; few cumuli; wind.
	4:05	0.453	(?) 1	61 15	...	81 15	.32	28	40	0.709	Cumuli.
4	8:34	0.793	...	51 30	16 21	75 05	.57	16	61	0.632	Streaky haze.
5	8:45	0.785	...	48 45	16 03	73 15	.67	14	67	0.630	Haze along horizon.
	3:39	0.591	8	54 45	...	76 45	.72	22	46	0.624	
6	11:13	1.128	...	11 45	15 45	58 35	.83	23	46	0.651	Haze.
7	8:42	0.594	...	49 30	15 26	73 10	.62	21	60	0.776	
8	1:39	0.467	...	24 45	15 08	61 25	.16	23	50	0.709	Cumuli; dust; readings variable.
9	1:43	1.150	...	25 45	14 48	61 25	.19	36	50	1.228	Fine sky.
10	3:49	0.837	...	57 15	14 29	77 05	.40	36	46	1.130	Do.
11	8:20	0.844	...	55 0	14 10	75 25	.56	16	61	0.632	Do.
	8:48	0.929	...	48 0	...	71 20	.56	17	57	0.615	Do.
	11:57	1.183	...	0 45	...	56 00	.54	23	44	0.625	Do.
13	1:36	1.108	...	24 0	13 30	59 35	.52	33	40	0.878	
	2:46	0.981	...	41 30	...	67 15	.52	33	37	0.812	Stratus near horizon.
14	8:53	1.008	...	46 45	13 10	69 50	.78	27	70	1.188	Blue sky; haze very light.
	11:07	1.162	...	13 15	...	56 20	.79	33	59	1.294	
	11:47	1.132	...	3 15	...	55 05	.77	35	55	1.302	Very blue sky.
	1:35	1.175	...	23 45	...	59 10	.75	37	45	1.148	Traces of haze under sun.
	2:51	1.074	...	42 45	...	67 35	.74	38	43	1.135	Light haze under sun.
15	12:00	0.955	(?) 1	00 00	12 49	29 00	.86	37	27	0.688	Clouds over sun; readings variable.
19	2:53	1.043	...	43 15	11 26	66 25	.44	25	54	0.838	Light haze; wind.
	4:17	0.751	...	64 15	...	79 20	.49	26	54	0.876	
20	11:45	1.186	...	3 45	11 04	53 00	.91	32	50	1.056	Fine sky.
23	10:38	1.182	...	20 30	9 59	55 10	.74	27	54	0.916	Blue sky.
25	11:43	0.966	...	4 15	9 15	51 15	.89	39	98	2.689	Cloudy all day; readings variable.
27	2:28	0.369	...	37 0	8 30	60 40	.57	46	79	2.796	Through clouds; readings variable.
March 1	9:58	0.454	(?) 3	30 30	7 45	56 55	.50	48	86	3.144	Cirrus; stratus over sun; readings variable.
	2:33	0.793	...	38 15	...	60 40	.48	47	(?) 65	(?) 2.383	Haze and small cumuli.
4	8:36	0.921	...	51 0	6 36	67 05	.56	33	62	1.360	Light haze; small cumuli.
6	2:36	1.157	...	39 0	5 50	59 25	.68	35	44	1.042	Fine sky.
	4:37	0.737	...	69 15	...	78 45	.76	35	42	0.994	Do.
7	8:29	0.713	...	52 45	5 27	67 20	30.01	33	60	1.316	Morning haze light.
	8:50	0.718	...	47 30	...	64 00	.01	34	57	1.298	
	10:22	0.933	...	24 30	...	52 20	.00	40	54	1.538	Sun slightly hazy.
	11:08	0.971	...	13 00	...	48 45	.00	41	53	1.567	Light clouds; sun clear.
	12:42	0.988	...	10 30	...	48 15	29.97	44	50	1.647	Cirro-stratus over sun.
8	11:03	0.163	...	14 15	5 03	48 40	30.23	42	79	2.727	Clouds; readings very variable.
10	9:40	1.022	...	35 0	4 17	56 00	29.83	41	63	1.830	Small cumuli.
	11:57	1.098	...	0 45	...	46 15	.85	43	56	1.778	Small cumuli in a fine sky.
	2:02	1.122	...	30 30	...	53 50	.87	44	52	1.713	Fine sky.
11	2:49	0.853	...	42 15	3 53	59 40	30.06	39	85	2.334	Fleecy clouds.
	4:29	0.175	...	67 15	...	76 00	.04	38	87	2.302	
14	10:05	1.226	...	28 45	2 42	51 35	29.98	38	41	1.084	Fine sky.
	3:23	1.190	...	50 45	...	63 55	30.07	41	35	1.034	Do.
15	12:05	1.363	...	1 15	2 19	44 10	.25	46	56	1.983	Cirrus near horizon; wind.
18	10:02	1.175	...	29 30	1 08	50 35	29.74	36	40	0.983	Fine sky; traces of low haze.
	11:18	1.213	...	10 30	...	44 0	.72	37	39	0.994	Fine sky.
	11:56	1.207	...	1 0	...	43 0	.72	39	38	1.043	Do.
	12:57	1.183	...	14 15	...	44 50	.70	39	38	1.043	Few scattered clouds.
					(North.)						
23	2:06	1.246	...	31 30	0 51	49 50	.67	60	39	2.241	Blue sky; many cumuli.
24	8:46	1.181	...	48 30	1 15	59 30	.73	46	56	1.983	Fine sky.
	10:42	1.265	...	19 30	...	44 15	.72	47	50	1.834	Big cumuli; sun clear.
	12:36	1.328	...	9 0	...	41 25	.70	48	43	1.634	Small cumuli; sun clear.
25	1:57	1.177	...	29 15	1 38	48 00	.85	48	47	1.786	Light stratus; sun nearly clear.

TABLE 3.—*Observations of solar radiation*—Continued.

Date.	T.	Q.	N.	ϑ.	δ.	Z.	Barometer.	Temperature.	Relative humidity.	Absolute humidity.	Weather.
					(South.)						
1902.	h. m.			° ′	° ′	° ′	Inches.	° F.	Per cent.	Grs. cu. ft.	
March 25	5:13	0.601	....	78 15	....	80 10	.87	45	51	1.741	Good sky.
26	1:14	1.183	....	18 30	2 02	43 10	30.04	46	55	1.593	
31	10:57	1.213	....	15 45	3 59	40 25	29.21	51	46	1.943	Cumuli; sun clear.
April 1	3:07	0.549	(?) 1	46 45	4 22	55 55	.08	48	38	1.444	Cumuli; readings variable.
6	10:02	1.039	(?) 1	29 30	6 17	44 10	.73	52	46	1.573	Light clouds; batteries bad.
15	12:39	1.270	....	9 45	9 36	33 20	.84	51	37	1.563	Fine sky.
	2:30	1.195	....	37 30	....	46 05	.81	55	34	1.653	Do.
17	9:09	1.034	....	42 45	10 19	48 50	.74	50	46	1.874	Heavy haze near horizon.
19	10:34	1.131	....	21 30	11 01	36 05	.85	54	40	1.874	Uniform haze.
	11:44	1.063	....	4 0	....	31 00	.83	54	38	1.780	Streaky haze.
	1:06	1.096	....	16 30	....	34 00	.82	55	35	1.698	Bluish haze.
	2:59	1.016	....	44 45	....	49 40	.81	53	51	2.308	Uniform haze.
	4:43	0.718	....	70 45	....	68 20	.81	51	60	2.533	Haze.
	5:35	0.357	....	83 45	....	78 05	.82	50	70	2.853	Do.
20	3:18	0.691	....	49 30	11 22	52 45	.80	53	71	3.213	Haze; few cumuli.
21	11:14	0.575	....	11 30	11 42	31 45	.83	58	57	3.060	
23	12:06	1.117	(?) 2	1 30	12 23	29 30	.64	56	73	3.661	Clouds; readings very variable.
25	8:36	1.108	....	51 0	13 02	52 35	30.03	48	52	1.976	Light fleecy haze.
	12:27	1.022	....	6 45	....	29 25	29.99	53	54	2.403	Light cirrus.
28	3:45	0.882	....	56 15	14 0	55 45	.84	68	29	2.169	Cumulo-stratus.
May 2	9:00	1.145	....	45 0	15 14	46 50	.90	55	58	2.812	
4	10:23	1.237	....	24 15	15 50	33 20	.98	57	51	2.648	Fine sky.
6	9:12	1.207	....	42 0	16 24	44 00	.93	59	36	1.998	Do.
	2:37	0.597	(?) 1	39 15	....	47 55	.88	59	66	3.666	Cloud over sun.
10	3:03	0.768	....	45 45	17 30	45 50	.80	50	35	1.427	Haze.
11	12:35	1.302	....	8 45	17 46	25 10	.93	56	32	1.605	Fine sky.
16	12:17	1.148	(?) 1	4 15	18 59	23 05	.85	63	35	2.223	Few fleecy cumuli; batteries bad.
18	1:20	1.020	....	20 0	19 27	28 05	.73	69	40	3.090	Hazy.
23	10:54	1.033	....	16 30	20 29	25 30	.67	78	54	5.550	Very light cirrus; oppressively hot.
31	9:03	1.170	....	44 15	21 51	42 00	30.18	58	50	2.685	Blue sky.
	2:10	1.210	....	32 30	....	33 45	.17	68	34	2.544	
June 1	11:30	1.159	....	7 30	22 0	20 50	.23	65	59	4.001	Bluish white sky.
5	11:30	1.191	....	7 30	22 30	20 20	29.84	61	55	3.268	Blue sky; small cumuli.
9	9:58	1.251	....	30 30	22 54	31 40	.72	59	50	2.778	Blue sky; light haze near horizon.
11	8:00	1.092	....	60 0	23 03	52 50	.72	56	65	3.261	Bluish sky; heavy haze near horizon.
	10:08	1.158	....	28 0	....	29 55	.72	59	58	3.242	Do.
24	11:50	1.240	....	2 30	23 26	18 30	.75	63	53	3.364	Cumuli.
*July 4	12:02	1.173	....	0 30	22 56	18 55	.75	70	44	3.512	Cumuli (2).
5	3:36	0.928	....	54 0	22 51	48 30	.65	71	48	3.956	Fleecy stratus (1).
	4:52	0.771	....	73 0	....	62 00	.64	73	44	3.825	Stratus (1); light haze over sun.
9	8:41	0.743	....	49 45	22 26	45 35	.78	77	70	6.973	Cirrus (3); haze over sun.
11	8:44	1.136	(?) 1	49 00	22 11	45 10	.83	67	57	4.128	Batteries bad.
12	8:57	0.832	....	45 45	22 03	42 55	.86	72	50	4.254	Cirro-cumulus near sun.
	11:30	1.098	....	7 30	....	20 45	.83	76	40	3.862	Cumuli (4).
	12:21	1.139	(?) 1	5 15	....	20 15	.82	77	38	3.786	Cumuli (5); batteries bad.
13	7:02	0.765	....	74 30	21 55	64 20	.77	67	89	6.474	Blue sky; some haze.
	7:27	0.825	....	68 15	....	59 40	.78	74	86	7.795	Blue sky; haze over sun.
	8:00	0.889	....	60 0	....	53 30	.79	70	75	5.985	Do.
	8:32	0.949	....	52 0	....	47 35	.80	72	65	5.531	Blue sky; few cumuli in southeast.
	9:01	1.016	....	44 45	....	42 15	.80	73	60	5.269	White haze up to sun.
	9:44	1.067	....	34 0	....	34 40	.80	74	50	4.533	Clear sky.
	10:32	1.134	....	22 0	....	27 20	.80	76	48	4.634	Perfectly clear.
	11:07	1.116	....	13 15	....	22 50	.80	76	47	4.537	Do.
	12:04	1.137	....	1 0	....	19 55	.78	78	44	4.523	Do.
	12:53	1.082	....	13 15	....	22 50	.78	80	40	4.374	Very few small cumuli.
	1:40	1.118	....	25 0	....	28 55	.77	81	38	4.284	Do.
	2:20	1.136	....	35 0	....	35 25	.76	81	37	4.171	Do.
	2:56	1.082	....	44 0	....	41 45	.76	81	37	4.171	Do.
	3:34	1.035	....	53 30	....	48 40	.75	82	38	4.418	Light haze.
	4:13	0.860	....	63 15	....	55 55	.75	82	37	4.302	Haze over sun; readings variable.
	4:56	0.918	....	74 0	....	63 55	.74	82	37	4.302	Haze in west.
14	7:01	0.629	....	74 45	21 46	64 35	.79	71	82	6.756	Heavy haze.
	7:52	0.832	....	62 0	....	56 05	.80	74	71	6.437	Do.
	8:53	0.939	....	46 45	....	43 50	.80	79	55	5.830	
	11:25	1.100	....	8 45	....	21 20	.77	83	47	5.634	Clear sky; breeze.
	12:14	1.106	....	3 30	....	20 15	.75	84	48	5.930	
	12:54	1.042	....	13 30	....	23 05	.74	85	46	5.860	
	1:54	0.975	....	28 30	....	31 10	.73	85	45	5.731	Clear sky; horizon hazy.
	2:35	1.001	(?) 1	38 45	....	38 05	.73	86	45	5.908	Rheostat working badly.
	2:53	0.826	....	43 15	....	41 20	.72	86	45	5.908	Hazy; some cirrus cloud.
	4:09	0.814	....	62 15	....	55 15	.71	86	46	6.030	Hazy near sun; cirrus.
	4:43	0.579	....	70 45	....	61 35	.70	85	50	6.368	Heavy haze in west.
15	7:51	0.709	....	62 15	21 37	55 20	.70	69	90	6.953	Heavy haze in east.
	8:59	0.792	....	45 15	....	42 50	.65	76	73	7.049	Heavy haze in east; cirrus.
	10:38	0.828	....	20 30	....	26 35	.63	79	69	7.315	Do. Do.
	11:42	0.962	....	4 30	....	20 35	.60	79	68	7.199	Haze lighter; readings variable.
28	9:29	0.723	....	37 45	19 07	39 10	.73	74	88	7.977	Heavy haze.
29	1:16	0.849	....	19 0	18 53	28 05	.69	81	63	7.104	Cumuli (2) and haze.
31	9:05	1.000	....	43 45	18 24	43 50	.85	75	55	5.146	Haze; cirrus (1).
	10:07	1.005	....	28 15	....	33 35	.85	77	44	4.385	
	11:01	1.070	....	14 45	....	26 35	.85	80	45	4.921	No clouds; hazy.
	1:47	0.901	....	26 45	....	32 40	.83	81	40	4.510	Hazy.
	2:57	0.802	....	44 15	....	44 10	.82	80	46	5.030	Do.
	4:46	0.757	....	71 30	....	64 15	.80	78	47	4.829	No clouds; horizon hazy.
August 1	7:16	0.616	....	71 0	18 09	64 00	.81	68	69	5.161	Cirro-cumuli (5); haze over sun.
	9:15	0.926	....	41 15	....	42 15	.81	74	57	5.077	Cirro-cumuli (8); readings variable.
2	9:05	0.709	....	43 45	17 54	44 10	.75	75	75	7.017	Cumuli (3); light clouds over sun.
9	8:32	1.032	(?) 1	52 0	16 00	51 20	.77	70	67	5.340	Horizon hazy.
13	8:49	1.149	(?) 1	47 45	14 50	49 05	.89	60	56	3.217	Clear.
	9:47	1.242	....	33 15	....	39 20	.88	62	49	3.010	Do.
	10:48	1.230	....	18 0	....	31 10	.87	63	49	3.111	Do.
	11:54	1.207	....	1 30	....	27 00	.85	66	46	3.224	Do.
	12:51	1.207	....	12 45	....	29 10	.85	67	44	3.186	Do.
	1:54	1.181	....	28 30	....	36 30	.84	69	42	3.244	Do.
	3:16	1.175	(?) 3	49 0	....	50 00	.82	70	41	3.272	No clouds; haze in west.
14	8:19	1.031	....	55 15	14 31	54 40	.86	66	58	4.065	Heavy haze; cirrus (3).
	9:17	1.069	....	40 45	....	44 30	.86	69	50	3.863	Heavy haze; cirrus.
	10:14	0.719	....	26 30	....	35 40	.86	71	48	3.955	Heavy haze over sun; readings variable.
	10:31	1.116	....	22 15	....	33 25	.85	72	48	4.084	Heavy haze over sun (7); readings variable.
	12:35	0.824	....	8 45	....	28 20	.84	72	46	3.914	Heavy haze; cirrus (7).
15	8:40	0.853	....	50 0	14 13	51 05	.73	73	67	5.883	Heavy haze; cirrus (4).
	10:13	0.854	....	26 45	....	36 00	.72	74	55	4.986	Cumuli (5).
16	12:23	1.176	(?) 2	5 45	13 54	28 25	.62	64	50	3.282	Cumuli (5); sun partly covered.
	2:44	1.156	....	41 0	....	45 05	.60	67	46	3.330	Cumuli (3).
18	12:25	1.060	....	6 15	13 16	29 05	.61	69	62	4.780	Cirro-cumuli (4).

TABLE 3.—*Observations of solar radiation*—Continued.

Date.	T.	Q.	N.	ϑ.	δ.	Z.	Barometer.	Temperature.	Relative humidity.	Absolute humidity.	Weather.
					(South.)						
1902.	h. m.			° ′	° ′	° ′	Inches.	° F.	Per cent.	Grs. cu. ft.	
August 20	7:44	0.914	...	64 0	12 37	62 20	.74	65	76	5.154	No clouds; haze.
	8:50	1.102	...	47 30	...	50 25	.74	66	63	2.313	Fine sky.
	9:44	1.064	...	34 0	...	41 35	.75	68	59	4.414	Fine cirrus over sun.
	10:44	1.093	...	19 0	...	33 35	.75	69	55	4.250	Cumuli (3); readings variable.
	11:51	1.076	...	2 15	...	29 15	.75	71	50	4.120	Cumuli (6); readings variable.
	1:25	1.040	...	21 15	...	34 35	.75	72	47	3.999	Cumuli (4).
25	9:02	1.048	...	44 30	10 56	49 35	.78	68	67	5.012	Few cumuli.
	10:03	1.109	...	29 15	...	40 05	.77	69	61	4.713	Cumuli (5).
	10:56	1.166	...	16 0	...	33 55	.75	70	54	4.309	Cumuli (3).
26	7:22	0.840	...	69 30	10 36	67 45	.71	62	84	5.160	No clouds; some haze.
	8:28	0.915	...	53 0	...	55 40	.71	67	72	5.214	Clear.
	9:32	1.083	...	37 0	...	45 00	.71	70	64	5.107	Do.
	10:32	1.127	...	22 0	...	36 40	.71	73	55	4.830	Do.
	11:37	1.103	...	5 45	...	31 40	.70	74	51	4.624	Few cumuli.
	12:27	1.142	...	6 45	...	31 45	.69	76	50	4.828	Cumuli (2).
	2:27	1.053	...	36 45	...	44 50	.67	78	45	4.625	Do.
	3:31	0.973	...	52 45	...	55 30	.66	78	45	4.625	Cumuli (1).
27	6:37	0.352	...	80 45	10 15	76 20	.73	62	89	5.467	Heavy haze near sun.
	6:55	0.452	...	76 15	...	73 00	.74	63	85	5.397	Haze over sun.
	7:21	0.625	...	69 45	...	68 10	.74	66	80	5.607	Haze.
31	10:04	0.740	...	29 0	8 50	41 45	.88	70	69	5.506	Heavy haze.
	11:01	0.813	...	14 45	...	35 30	.86	74	64	5.798	Do.
	12:11	0.783	...	2 45	...	33 05	.85	78	63	6.473	Heavy haze; readings variable.
	1:38	0.858	...	24 30	...	39 25	.83	78	67	6.887	Some cirrus; haze over sun.
	2:44	0.908	...	41 0	...	48 50	.80	76	70	6.758	Do.
	3:49	0.519	...	57 15	...	59 55	.79	75	75	7.017	Some cirrus; heavy haze.
September 1	7:54	0.548	...	61 0	8 28	62 55	.77	73	91	7.992	No clouds; haze over sun.
	8:43	0.673	...	49 15	...	54 35	.76	77	73	7.272	No clouds; very hazy day.
	10:23	0.815	...	24 15	...	39 40	.76	80	63	6.889	Do.
	11:29	0.825	...	7 45	...	34 05	.75	83	56	6.715	Do.
	12:42	0.799	...	4 30	...	33 35	.73	83	46	5.516	Do.
	2:22	0.794	...	35 30	...	45 45	.70	84	47	5.807	No clouds; haze.
3	8:00	0.970	(?) 3	60 0	7 44	62 40	.85	65	67	4.543	No clouds; haze over sun.
	8:56	1.059	...	46 0	...	52 55	.86	70	55	4.389	No clouds.
	10:01	1.069	...	29 45	...	43 05	.87	72	51	4.339	Do.
	11:05	1.139	...	13 45	...	36 10	.86	73	49	4.303	No clouds; wind.
	11:51	1.168	...	2 15	...	34 10	.85	73	46	4.040	No clouds; gusty wind.
	1:32	1.150	...	23 0	...	39 40	.84	74	44	3.988	No clouds; readings variable.
5*	8:40	1.130	...	50 0	7 00	56 10	.80	60	63	3.620	Fine sky.
16	1:55	0.786	...	28 45	2 50	46 45	30.04	67	40	2.896	Blue sky; light streaky haze.
	2:48	0.775	8	42 0	...	54 10	.03	66	41	2.874	Do.
	4:23	0.372	...	65 45	...	70 10	.03	65	42	2.849	Do.
	5:04	0.298	...	76 0	...	77 40	.03	64	45	2.954	Do.
17	8:31	0.348	...	52 15	2 27	61 00	.12	55	91	4.413	Bluish sky; haze.
	11:04	0.698	...	14 0	...	41 20	.12	65	63	4.272	Do.
	12:43	0.801	...	10 45	...	40 35	.10	67	45	3.258	Bluish sky; haze heavier.
	1:40	0.737	...	25 0	...	45 20	.10	67	44	3.184	Do.
	2:35	0.603	...	38 45	...	52 30	.09	66	45	3.206	Do.
	3:01	0.548	...	45 15	...	56 25	.09	66	46	3.224	Do.
	4:49	0.250	...	72 15	...	75 10	.09	64	57	3.742	Bluish sky; haze streaky.
	5:04	0.175	...	76 0	...	78 00	.09	63	59	3.745	Bluish sky; haze quite heavy.
23	9:45	0.852	...	33 45	0 07	51 35	29.76	63	84	5.333	Bluish sky; some haze.
	12:27	0.961	...	6 45	...	42 10	.72	72	51	4.479	Bluish sky (oppressively hot).
	2:55	0.858	...	43 45	...	57 20	.69	73	52	4.567	Bluish sky; few cumuli.
					(South).						
24	7:39	0.510	...	65 15	0 16	72 00	.72	65	90	6.104	Bluish sky; clouds near horizon.
	8:32	0.670	...	52 0	...	62 55	.72	68	85	6.358	Do.
28	10:44	0.852	...	19 0	1 50	46 55	.59	71	73	6.015	Do.
	12:42	0.970	(?) 2	10 30	...	44 40	.57	71	74	6.098	Scattered clouds; readings variable.
	12:53	0.243	(?) 2	13 15	...	45 15	.56	71	74	6.098	Through a cloud.

* The observations of July 4 to September 5, inclusive, were made by Mr. Robinson Pierce, jr.; all others by Mr. H. N. Davis.

sor Upton, and those taken at the Hope Reservoir for the city engineer. These stations are quite close to each other and to both places at which observations were made; and since the continuous record sheets were more accessible at the former place, and were found upon comparison to agree reasonably with the tabular synopsis published by the city engineer they have been used.

The barometer readings are in inches and are not reduced to sea level. The instrument is 214 feet above sea level. The relative humidity and temperature (t) are also taken from the continuous records, and these as well as the barometer readings are compared once a day with standard instruments. The absolute humidity is given in grains per cubic foot, and is calculated from relative humidity and temperature by means of the tables[5] supplied by the Weather Bureau. In the last column are given such cloud notes as were made at the time of each observation. In general the term cumulus was accurately used, while cirrus and stratus were applied more loosely, the first to wispy, the second to sheet forms, and should not be relied upon too literally. Where figures are given they indicate the amount of sky covered, in tenths.

It seems hardly worth while to attempt a direct determination of the solar constant itself by the usual methods from these data, for morning observations in Providence are almost always influenced by a heavy haze on the horizon, and very rarely are conditions even approximately uniform throughout any considerable portion of a day. Their chief value would appear to be more strictly meteorological, and it is hoped that they and such others of the same kind as may have been collected by the Bureau may be discussed from this point of view.

[5] "Psychrometric Tables, etc.," prepared by Prof. C. F. Marvin. Washington, 1900. Table XII, pp. 83–84.

RECENT PAPERS BEARING ON METEOROLOGY.

W. F. R. PHILLIPS, in charge of Library, etc.

The subjoined titles have been selected from the contents of the periodicals and serials recently received in the library of the Weather Bureau. The titles selected are of papers or other communications bearing on meteorology or cognate branches of science. This is not a complete index of the meteorological contents of all the journals from which it has been compiled; it shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau. Unsigned articles are indicated by a ——.

Science. New York. N. S. Vol. 17.

Clayton, H. H. [Review of] Handbook of Climatology. Part 1. General Climatology. By Dr. Julius Hann. Translated by Robert DeCourcy Ward. Pp. 819–820.